VOLUME XXXIII NUMBER 4 WHOLE NUMBER 283

THE JOURNAL

OF

THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

EDITOR, C. A. CHANT ASSISTANT EDITOR, F. S. HOGG
David Dunlap Observatory
Richmond Hill P.O., Ont.

ASSOCIATE EDITORS

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Ottawa

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Director of the Dominion Astrophysical Observatory
Victoria, B.C.

J. PATTERSON
Controller of the Meteorological Service of Canada, Toronto

PUBLISHED MONTHLY
(*Ten numbers per year*)

April, 1939

PRINTED FOR THE SOCIETY
TORONTO: 198 COLLEGE ST.

THE JOURNAL
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Articles PAGE

The Seismic Method of Prospecting (with Plates III, IV, V) ..... *Ernest A. Hodgson* 121

Nuclear Disintegration ..... *Elizabeth J. Allin* 151

Meteor News

Observations of the Orionid and Geminid Meteors, 1938 ..... *P.M.M.* 162

Review of Publications

Variable Stars, by Cecilia Payne-Gaposchkin and Sergei Gaposchkin (*F.S.H.*) 164

Notes and Queries

The Bright Aurora of February 24, 1939 (*J.F.H.*)—The Ptolemaic and Copernican Theories—A Few Florida Notes (*C.A.C.*)—Harvard Summer Conference on Astronomy—Preservation of Herschel's Observatory House—The Buhl Planetarium at Pittsburgh—Comet Väisälä, 1939b—Not in Florida (with Plate VI) (*F.S.H.*) 166

Meetings of the Society

At Vancouver—At Victoria—At Toronto 172

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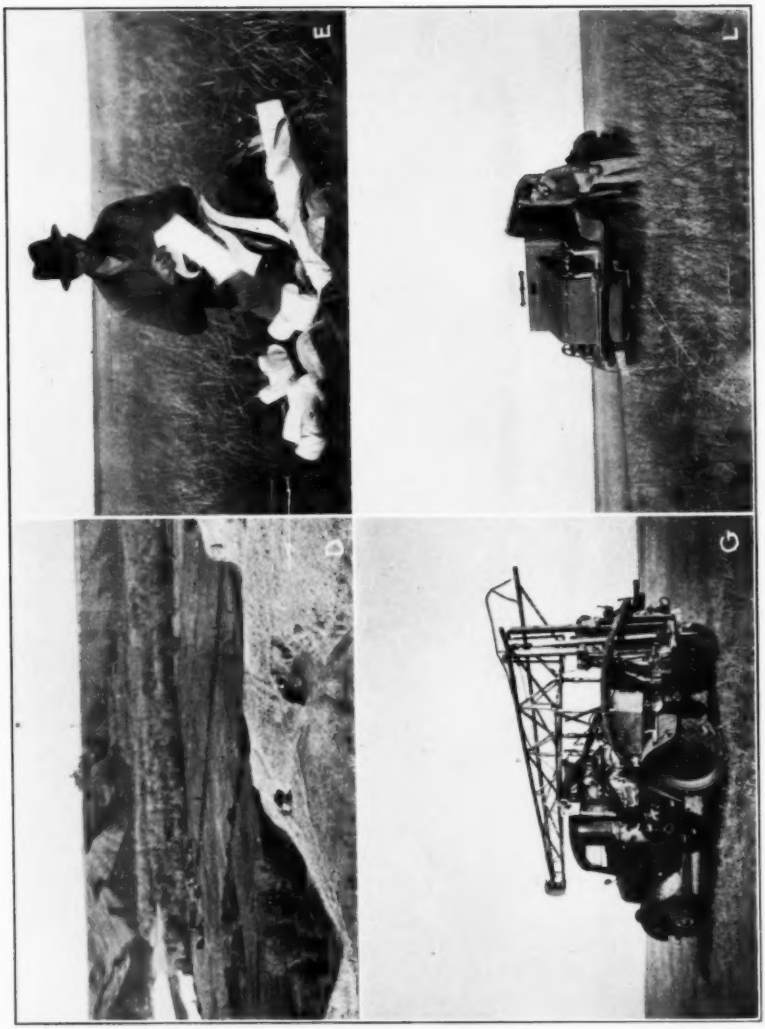
PLATE III

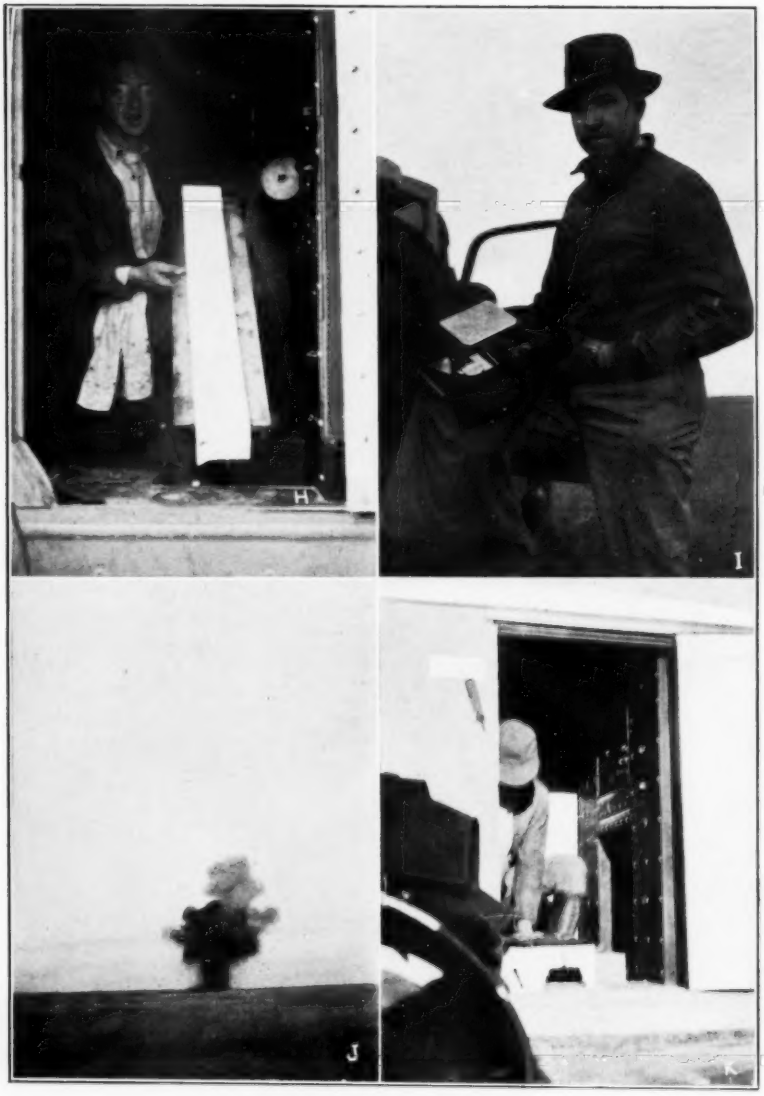
A.—Loading dynamite into shot hole.
B.—Digging geophone emplacements during heavy wind.
C.—Drill truck with mast raised.
F.—The Vertical Velocity, spread (extends to 3,400 ft.).

PLATE IV



D.—Typical River Plain, at Lethbridge, Alberta.
E.—A morning's set of records.
G.—Drill truck ready for the road.
L.—Recording truck, showing cable reels.

PLATE V



H.—Exhibiting freshly made record.
I.—Amplifier unit, removed from recorder truck.
J.—A typical weathering shot.
K.—Warming the developer in cold weather.

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THE SEISMIC METHOD OF PROSPECTING

By ERNEST A. HODGSON

(with Plates III, IV, V)

THE following description of seismic prospecting is based on the modifications of that method as practiced by one company in a single area in southern Alberta. It must be borne in mind in following through this presentation that, in such a survey, various problems arise which, for their solution, require the judgment of experienced operators and the exercise of considerable ingenuity in devising and applying special procedures and corrections. Space here permits only a general description of the usual routine work.

Other geological conditions would require slightly different routine. The routine observations by other companies, in this or in other areas, would vary slightly according to the equipment used by them and their judgment as to the best way of attacking the many-sided problems which develop as the work proceeds. With the above limitations in mind, this report may be taken as a general outline of the application of this method of geophysics to the search for petroleum.

1. *The Field Problem:* Petroleum is located in certain strata at various depths. Usually it is associated with gas and water. If the stratum or *horizon*, in which this combination of oil, gas, and water is found, should, at any point, have an area higher than its general level, so that the contours showing the variations in elevation over that part of the horizon are closed, there is a possibility of a concentration of oil on the top or flanks of the *high* or *structure* so defined.

The field problem in seismic prospecting is to locate the positions of such structures, to delineate their extent, shape, and elevation above the general level of the horizon concerned and to determine the depth from the surface. The method cannot always be applied and, in any event, it can only define the structures, without indicating in any way whether they are associated with oil or gas. It selects the areas in which, alone, oil reservoirs may be found. Having selected them, only the drill will answer the question of whether oil or gas exists at the points selected.

2. *General Outline of the Method:* The area to be surveyed is first examined by a geologist. All geological information, available in previously published reports, is assembled. A topographical map of the field is desirable. Bench marks, carried forward by a geodetic or topographical survey and showing elevations with respect to sea-level at a multiplicity of points, will greatly reduce the preliminary work required. The geologist responsible for the work is in the best position to indicate, initially, the possibilities of the field. He, together with the geophysicist in charge of the surveying, then plans the modifications of the seismic method required and decides where to begin the preliminary or reconnaissance survey.

Stripped of all details, the seismic method, applied at any single given point on the surface, indicates the elevation with respect to sea-level of the corresponding point or points vertically below, on the horizon or horizons under investigation. In reconnaissance work, it is usual to apply the method at a series of points in a straight line. A graph of the elevations so measured, when plotted to scale, is called a *profile*. A *reversal* on this profile may be defined as a peak elevation. Should such a reversal be found, steps are at once taken to run a second profile to cross the first approximately at right angles at the position of the peak. Should this profile also show a reversal at or about the same point, it may be concluded that the contours will close about the peak. A high, or structure, has been located.

Having found the structure, the geophysicist in charge must decide, in the light of the data already obtained and assisted by his previous experience, on the best positions for further depth tests to enable him to draw the contours which will define the newly-found

structure as regards position, extent, shape, and elevation above the general level of the horizon concerned. The number of positions to be occupied, or, in other words, the number of depth determinations to be made, will depend on the time and money available for the work and on the degree of definition asked for by those responsible for the survey.

At each step, the surveyor attached to the prospecting party must determine the position of each investigation point on a large-scale map of the field. This he begins when the survey is undertaken, carries forward as the survey progresses, and completes only when the survey closes. He must also determine the elevation with respect to sea-level of the surface position of each investigation point. The difference between the surface elevation for, say, the point vertically above the corresponding optimum point on the structure and the elevation of the latter is the measure of depth—the number of feet which the drill must penetrate to answer the question of whether or not an oil reservoir exists at the position located by the seismic survey.

Each investigation point consists of a *shot-hole* and a *spread*. A carefully selected amount of dynamite is exploded at a measured depth in a hole sunk by a portable rotary drill (see Plates III*C*, IV*G*). The energy liberated by the blast sets up elastic vibrations which travel down and out in all directions into the earth. A series of portable electric seismographs arranged in a particular pattern in line with the shot-hole is known as the *spread*. These seismographs record the arrival times of the earth tremors, by means of oscillographs or galvanometers, on a strip of rapidly-moving photographic paper of high sensitivity. The record so made indicates the arrival time of the energy which travelled along the surface and also that reflected from various horizons within the earth.

The time required to travel from any selected depth, say 5,000 feet, to a depth not quite at the surface, say within 50 feet, is found by experience to vary quite slowly for the same depth interval from point to point. The vertical velocities for the component parts of such a vertical path increase, in general, with depth. The total depth divided by the corresponding total time defines what is known as the *average vertical velocity*.

Neglecting the means by which the data are obtained, this velocity

may be said to be determined for various depths by the following graphical method. Depths are measured downward from a *datum plane*, defined with respect to sea-level and selected so that at no point does the surface descend within say 100 feet of the datum. Using rectangular co-ordinate paper, let the abscissæ represent depth below the datum and the ordinates the average velocity, i.e., the depth concerned, divided by the time required for the elastic waves to rise vertically from that depth. Several points having been determined by methods to be described later, intermediate values are read off from the graph line through the plotted points.

The time required for the elastic waves to traverse the last fifty feet or so at the surface varies considerably from point to point. This surface layer in which the vertical velocity varies so greatly is known as the *weathering* or the *weathered zone*; although, strictly speaking, weathering as generally understood cannot be considered the cause of the variation in velocity.

The elapsed time from the shot to the seismograph or *geophone* concerned is first corrected for the variable time spent in the weathered zone. The method by which this is done will be described later in detail. The elapsed time is further corrected for those parts of the ray path lying above the datum plane. To make the picture concrete let us consider the case of southern Alberta and select 3,000 feet above sea-level as the datum plane. Such a plane lies some 200 feet below the general surface of the area studied. The two corrections having been applied, there remains the elapsed time taken by the energy to travel from the datum plane, defined with respect to sea-level, to the reflecting horizon and back to the datum plane.

This path will be roughly V-shaped, the arms of the V being slightly convex outward. The width of the V at the datum plane can be determined from the measure of the spread (the distance from the shot point to the geophone) and from other considerations, such as the depth of the shot-hole, the thickness of the weathered layer, the depth of the datum plane below the surface, and the series of component vertical velocities below the datum plane. These last can be known only approximately unless a well log for the area is available. Correcting for these various conditions, the time required for the energy to travel from the reflecting horizon vertically to the datum

plane may be found. If the average velocity for this depth is known, the time may be translated into feet and the depth below datum of that point on the horizon roughly midway between the shot point and the geophone is found. It is to be remembered in plotting depth determinations that they are to be taken usually as defining the point midway between the shot point and the geophone concerned, not the position of the shot-hole.

If the reflecting layer is not parallel to the surface, the point for which the depth is defined is not at the above midway positions and, moreover, the application of the corrections mentioned in the previous paragraph must be modified. The application, in the field, of these corrections under both ordinary and more complex conditions is simplified by the use of nomographs prepared by the mathematical physicists directing the activities of the survey company.

3. *Organization of the Field Party:* A typical field party consists of about a dozen men: the party chief, the surveyor and surveyor's helper, the driller and driller's helper, the shooter and shooter's helper, the recorder and his assistant, and one or more computers, together with two or three other men who may be assigned to assist in particular positions more or less continuously or who may be shifted about according as varying conditions tend to slow up some particular part of the work.

Co-operation and good will among the various units of the party are absolutely essential to the success of the survey. Literally, the rate at which the party covers territory is that of its weakest unit. Moreover, the interpretation of the records requires the consideration of many factors. Unless all members of the group are capable, interested and anxious for the success of the work, some of these factors are bound to be overlooked. Native intelligence and resourcefulness are at a premium.

The pay offered by a good seismic survey outfit is good. The amounts vary according to the exact nature of the duties assigned a man on any given party. Sometimes the surveyor takes over some of the duties of a party chief, the other duties being shared between a party manager and the computer.

The automotive equipment consists usually of a passenger car for

the party chief, a light panel truck for the surveyors, a portable drill, a water truck, a dynamite truck, and a recorder truck.

The cost of equipping and operating a survey party varies according to the nature of the area under investigation and the type of equipment used. It requires approximately $30,000 to equip and operate a party for one month to get all in working order, and thereafter it costs from $3,500 to $4,000 a month to maintain it in the field. Survey parties may be hired as a unit, the charge varying from $7,000 to $9,000 per month.

4. *Survey Operations:* It has been stated that the work of the surveyor consists in locating in position and elevation all shot points and in carrying forward a map of the area under investigation. This is only part of his work. He must also determine the azimuth for each spread or layout of geophones from each shot-hole. He must mark these on the ground with wooden stakes carrying streamers of bunting. He measures the distance from the hole to each geophone. For example, one of the spreads used in Alberta was an *1,800-2,300 spread*. To mark this, the surveyor determines the azimuth, measures 200′ from the hole and plants a stake for a *weathering geophone* of which we shall say more later. At 1,800′ from the hole, and in the same line, he plants another stake for the first of six geophones. The positions of the rest of these are marked by stakes at distances 1,900′, 2,000′, 2,100′, 2,200′, and 2,300′, respectively.

The topographical map is compiled by means of a plane table and stadia. Distances along the spreads are chained. Elevations are carried from a bench mark to various spreads and back to close on the same bench mark. The elevation of each geophone position in every spread as well as the elevation of the top of the shot-hole must be determined and checked.

The surveyor must, in the course of his daily work, contact the men in the field and must be in touch daily with the party chief and the computer to know where, in the light of their increasing experience, they wish further work to be done. It is usual, therefore, to have the surveyor act as a liaison officer, conveying orders to the field men, bringing in records and reports, carrying the mail, etc.

In southern Alberta, the work of the surveyor was relatively

simple. There were few fences or trees to interfere with his work. The surface was gently rolling except at the rivers which are eroded deep into the drift. To cross these requires a descent of a hundred feet or so to the river plain, the fording of the rough gravel bed of the river, and the mounting on the opposite side of the steep bank. When the weather is dry this is not too difficult but in the case of rain the various truck units must stay together as much as possible to help in pulling each other out of tight spots.

The greatest help to the surveyor in southern Alberta is the government survey which covers the region. This survey literally divides the area into squares, half a mile to a side, with a location post at the corner of each. Each of these squares is a *quarter section.* Four make up a *section.* Thirty-six sections arranged in a square, six miles to a side, is a *township,* and a row of townships running north and south is called a *range.* The ranges are numbered westward from a selected meridian. The townships are numbered consecutively northward from the U.S. boundary. The sections are numbered according to the plan shown in Fig. 7 and the quarter sections are designated north-west, south-west, north-east, and south-east. Thus, the point "200′ east and 40′ north of the south-west corner of the SW quarter of section 21, township x, Range y, east of Meridian z" is definitely located in position. The elevations of the bench marks at the survey markers of the area are known, so the surveyor is able to locate his shot-holes and spreads in position and elevation by simply carrying a traverse from the nearest convenient corner post, checking back either on the same corner or at some other which he meets in his traverse. The rectangular grid of the survey forms a dimensioned basis for all the details of the topographical map under construction and the actual post markers in the field make it easy to re-locate any given position should further data from that point be found desirable.

5. *Drilling:* The drilling is done by means of a special rotary drill mounted on a sturdy truck. This truck can travel fifty miles an hour along the roads and can be taken across country over no roads at all. In transit, the drill mast is folded over the cab. On location, this is raised by hydraulic pressure and locked in position. The drill rod

is clamped in a collar rotated by the power take-off of the truck. This collar moves vertically 2′6″ so that the drill may be fed that far at each clamping. When the collar reaches the bottom of its run, the clamp is loosened and the collar shifted up 2′6″ on the drill rod. Each rod is 10′ long and weighs 50 lbs. When the rod length in place is used up in the hole, another length is screwed in place and the work goes on as before. Usually the bit is one used to break up the earth and shale removed; but, if conditions require it, core drilling may be done. Usually this is not necessary but sometimes lenses of hard sandstone are encountered which are only a few feet in thickness. These are cored and the drilling resumed beyond the lens.

Before beginning work, a sump hole is dug beside the truck and filled with water from the water truck. The drill pumps water from the sump down through the drill. This emerges at the bit and, flowing upward through the hole, washes out the detritus. During the progress of drilling the driller's helper samples the detritus. The depth is gauged by the number of lengths of rod in the hole. The driller records a log of the hole as the work progresses. As the hole is made deeper the water, used over and over, becomes muddier and its increasing specific gravity makes it better able to lift out the chips of rock. Sometimes commercial mud is added to attain this same end.

Sometimes a gravel bed is encountered and the hole *goes blind*. That is to say, the water is absorbed in the gravel and ceases to clean the hole. Sometimes the work may be continued by using commercial products designed to coat the hole with an impervious sheath. Sometimes the hole is lined with *casing*: lengths of pipe sunk as the drilling proceeds. The drill works inside the casing which is forced down as the gravel is removed. At times the hole, if not vitally necessary in that position, is abandoned under such conditions.

The drilling pressure is applied by hydraulic means at the collar. This is in the control of the driller. He must use care to sink the drill as rapidly as possible but must avoid jambing his equipment. Every foot of depth presents its special problems for the solution of which he is responsible. He must do his best to sink holes in the ground where the party chief and the computer want them on paper and he must keep ahead of the shooters and recorders. A competent driller is worth much to a survey party. This is recognized in the

pay often given them. There are instances where the driller was as well paid as the party chief.

In addition to drilling new holes, the driller must keep all holes open until they are fully shot. Thus he must often go back to holes he has drilled, set up in the same position as before and *clean out* the hole by rapid drilling. Some holes cave badly even with no shooting. Others cave after one or more shots although, for the success of the work, it is essential that more be fired there. The driller must make a hurried visit to the location and clean out the hole with as little lost time as possible.

In addition to his regular work, the driller must keep his equipment in working order, all break-downs repaired and his drills sharpened. Having the tools, he is thus often called upon for emergency repairs to other trucks in the field. He has a heavy winch on the back of his drill with which he can pull casings after a well is shot. But, he is liable to be called from his work to drive across the prairie several miles and use that same winch to pull the water truck out of the river or the party chief's car up a coulee. If he gets behind on his drilling, he perhaps works all night to get a hole ready for the shooters and recorders in the morning. The driller is, outstandingly, the one who can do much to make or mar the success of a seismic survey.

6. *Shooting:* Shooting is done by one man who is responsible for the handling of all the explosives used. The dynamite comes in cylinders of brown paper 2″ in diameter, and 16″ long, weighing 2½ lbs. The amount to be used is ordered by the recorder and is determined by measure by the shooter. Fractions of a stick are cut off by a sharp knife, the dynamite being about the consistency of cheese. If more than a whole stick is used the several lengths of cylinder are fastened together by means of wooden plugs sharpened at both ends and driven into the adjacent ends of sticks. The firing cap is placed in a hole punched with a wooden punch in the side of the lowest section. The cap wires, carefully shorted at their outer ends to preclude premature firing, are carried in a half hitch around the lowest section, up and about each of the others in a half hitch and so up the loading rod.

The loading rods are of wood each ten feet long and equipped for locking successive units together in such a way that a rotation of the top rod carries down the whole string and that the string will transmit either a thrust or a pull. The coupling device is simple and effective and successive poles are hooked in place as fast as they can be lifted to a vertical position.

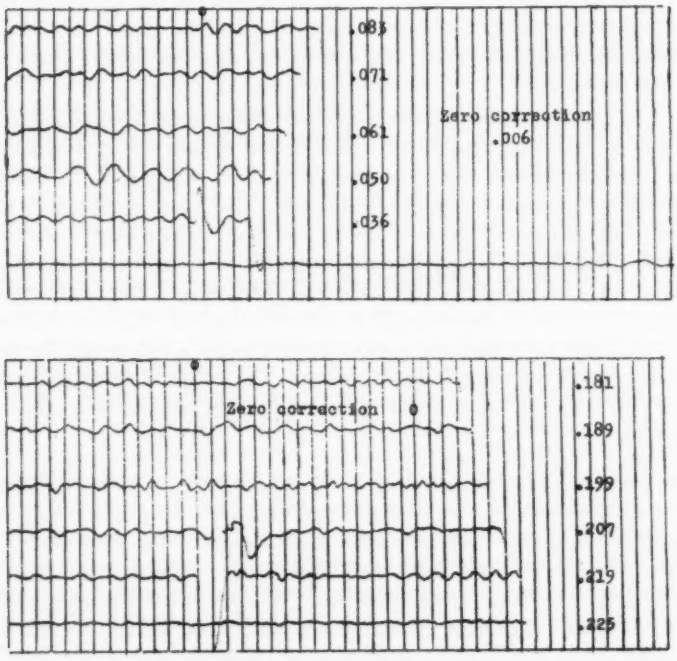


Fig. 1.—Weathering Shots.

In loading a hole the dynamite cylinder, simple or multiple, is held by a pair of clamps on the first loading pole. As the hole is full of water the pole and its dynamite must be thrust down. One man feeds in the cap wires and two others manipulate the poles. (See Plate III*A*.) If a boulder juts out into the hole from the side wall

the dynamite must be forced past. Sometimes this takes the full pressure of two men jambing downward on the poles.

When the charge is at the depth ordered by the recorder, it is dislodged from the poles by a quick jerk. Then the poles are lifted gently while the man with the cap wires pulls up gently. If the wires do not come readily the charge is free of the poles and these are drawn

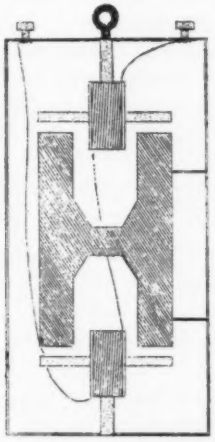


Fig. 2. — Schematic Diagram Showing Principle of Geophone Construction.

out of the hole. The firing line is attached to the now separated ends of the cap wires and all is in readiness.

The *blaster* is a mechanism which generates electricity, when a handle is thrust down in much the same manner as in an old-fashioned automobile tire pump. At the instant when the handle reaches firing position, contact is made and a high tension current fires the charge. An electric cable running from the blaster to the recorder truck, perhaps a quarter of a mile away along the spread, registers the instant of the blast on geophone No. 5, counting outward from the shot. No magnification is used and the disturbance caused

by the shot on the geophone record comes to rest before the earth tremors have time to reach that geophone.

A geophone placed close to the top of the shot-hole is connected into the record of geophone No. 4 in the same way that the shot line is connected into geophone No. 5. The records of the *shot time* and the *up-hole geophone time* may be seen on the diagram given in Fig. 1. The use of the up-hole geophone time will be discussed later.

The shot over, the shooting line is disconnected from the spent cap wires and re-loading begins as soon as orders for the amount and depth have been received from the recorder who is able to carry on a two-way telephone conversation with the driller, by means of the same

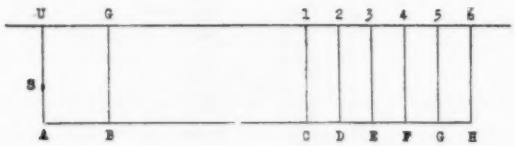


Fig. 3.—Assumed Paths in Weathering Computations.

cable as that used to record shot time on geophone No. 5. In sinking the second charge in a deep hole, the men are liable to be spattered with mud from the hole when their poles reach the pocket of compressed gas left in the bottom of the hole by the previous charge. Care is taken to avoid leaning over the hole, which bubbles and rumbles like a hot mud spring. The spent cap wires—in many cases sixty feet long and double—are valuable as copper. They are kept, the insulation burned off, and sold as copper scrap.

If the hole blows all its water out at any shot, it can be re-filled from a supply in a tank on the shooting truck. Sometimes in dry sections of the country it becomes quite a problem to secure enough water for the drilling and shooting. In Alberta there was plenty of water available in nearby rivers. In other sections every care is taken to conserve water. The use of commercial products such as *Aquagel* to produce an impervious casing in the hole becomes financially feasible. In one of the holes in Alberta the record reads "Hole went blind at 15 feet. Pumped 2,100 gallons into it." This was an exception

in the case of a hole which was very much needed for theoretical reasons. The efforts failed and the hole had to be abandoned after all.

The shooter must keep a record of the charges and depths at which they are shot for each hole. On each seismogram made, the recorder writes the same information. When both reports are received at the computing office, they are required to check.

A routine of handling dynamite and blasting caps is adopted and rigidly enforced. Although the dynamite is handled freely, and to some appearances carelessly, there is in reality little danger of

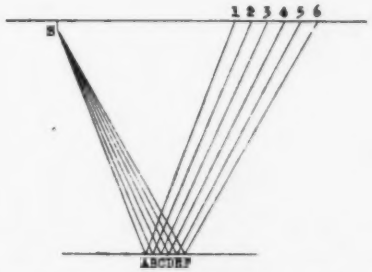


Fig. 4.—Assumed Paths for Reflected Rays.

accident. Every care is taken of the blasting caps, which are never broken out of their containers until the hole is actually being loaded. As said before, the ends of the wires from the caps are kept shorted until the charge is deep in the hole.

7. The Geophones: The portable seismographs or geophones are encased in cylinders about 5″ in diameter and a foot or so long. Externally, there are terminals for two wires, a zero adjusting screw, and an eye with a heavy cord to facilitate lifting the geophone from a deep hole. Inside, there is a heavy magnet in the form of an H, supported by thin flat springs projecting from the inside of the cylinder walls. When the casing receives a thrust in the direction of its long axis, normally set vertically, the magnet tends to lag behind. At the top and bottom of the inside of the cylinder, attached firmly to the walls, are two coils of wire connected together and to the

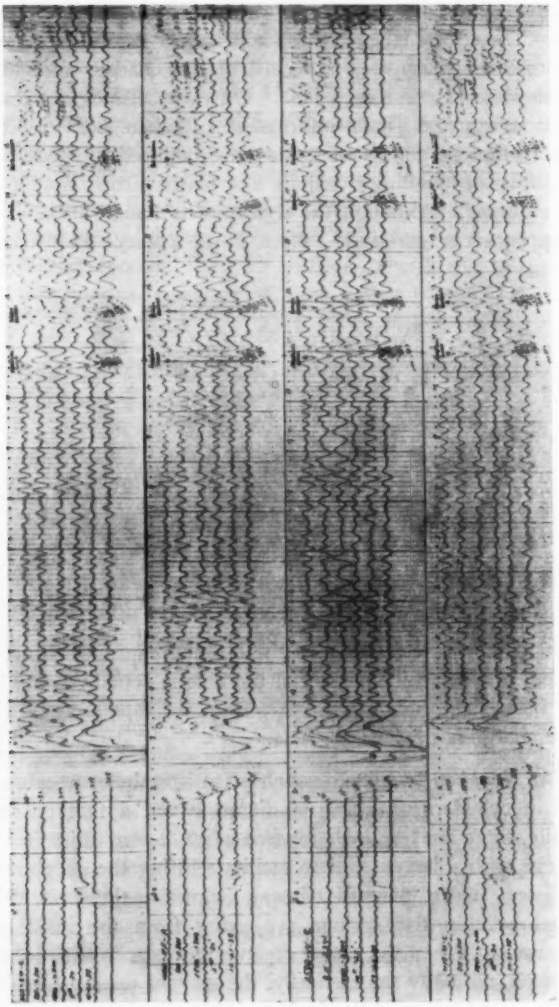


Fig. 5.—Set of Correlated Records.

external terminals. These coils surround iron cores which extend over the ends of the magnet as shown in Fig. 2.

As the geophone is subjected to vibrations, the space between the magnet poles and the cores of the coils changes, setting up electric currents in the wires. The wiring is designed to make the effects at top and bottom additive. The current generated in the coils is car-

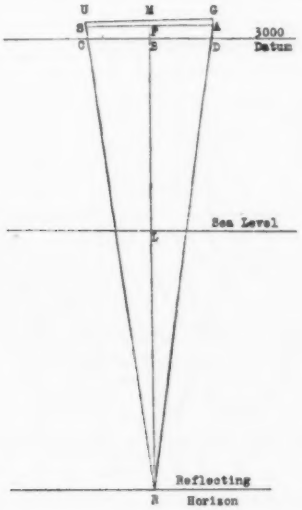


Fig. 6.—V Reflection drawn to Scale.

ried out by the terminal wires to be transmitted through amplifiers to the galvanometers on the recording truck. The cylinder is filled with grade 50 S.A.E. engine oil to damp the vibrations and bring the magnet to rest.

These geophones are very rugged, may be handled freely and are not too sensitive to slight variations from the true vertical in their placement on the ground. They are usually set in shallow holes about a foot deep, dug with post hole augers. When there is much wind, they must be set deeper, sometimes as much as six feet. See Plate III, *B*.

Care is taken to distinguish the polarity of the connections from geophone to galvanometer so that an upward thrust of the earth will register always the same way on the record. On the Alberta survey this was arranged to be downward as will be seen in the reproductions in Figs. 1 and 5.

8. *The Amplifier and Recorder:* For the Alberta survey a recording device using six galvanometers of d'Arsenval type was

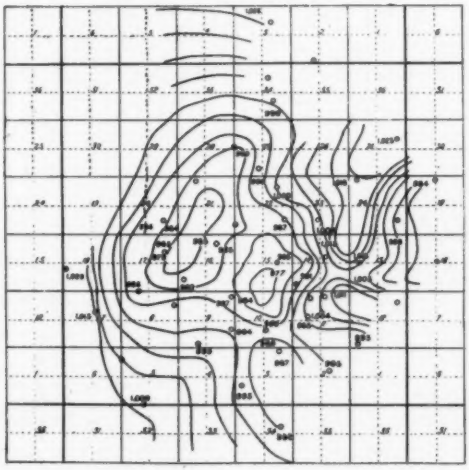


Fig. 7.—Contour Map of Seismic Survey. (This does not represent any actual survey.)

used. The same equipment could have been used with twelve galvanometers had it been decided that the larger number was desirable. Each galvanometer carries a small mirror. Light from a small electric bulb falls on the six mirrors of the galvanometers and is reflected back on a strip of photographic paper about 3 inches wide. This paper is very sensitive. It can be run at a rate of 15 inches per second and still give a clear black record of the galvanometer light spots. If the galvanometers are motionless, the light spots trace six straight black lines, parallel to each other and to the long axis of the

paper strip. If agitated by varying currents generated by the geophones, the mirrors are deflected and waves appear in the photographic traces.

A small cylindrical lens lies close to the moving strip of paper. It serves to bring to a spot focus the light from the galvanometer mirrors. It may also be illuminated as a whole, from end to end, by the light emitted from a lamp in a small rotating cylinder through any one of a series of small fine slits parallel to the axis of the cylinder and evenly spaced around it. There are ten slits in all, one

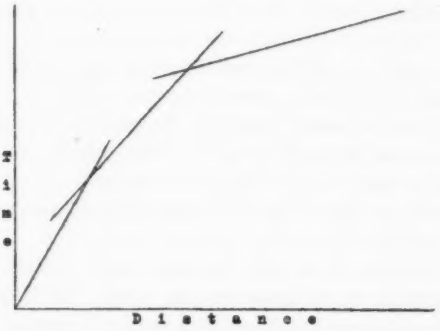


Fig. 8.—Arrival Times for Refraction Profile.

of them slightly wider than the others. The cylinder is rotated by a synchronous motor actuated by current controlled by a vibrating tuning fork. It turns one complete revolution in a tenth of a second. The fork is maintained in vibration by means of energy supplied by an electric device. Thus the cylinder rotates in such a manner that the cylindrical lens in front of the paper strip is flooded, for a brief instant at intervals of a hundredth of a second. Each time, a dark line is thereby registered clear across the strip of photographic paper. Every tenth line, at intervals of one tenth of a second is darker than the others. Samples of the records produced may be seen, in reduced facsimile in Fig. 5.

The geophones generate sufficient current to register, without recourse to amplifiers, the arrival times of the shot impulse and of the

up-hole geophone impulse on galvanometers 5 and 4 respectively, as explained in section 6 above. They also serve to supply a record of the first arrival times by the near surface path. If no form of amplification were used the energy supplied for the first several tenths of seconds afterwards would be so great that the galvanometers might be put out of commission and, at all events, would move so rapidly and so widely that the record would be lost. Then the energy by reflection paths would begin to come in and would be so feeble that, without amplification, the geophones receiving it would not generate sufficient current to make a legible record. Some form of *volume control* is evidently required. This is arranged by means of a very complex and efficient combination of radio valves which may be referred to as a series of six amplifiers having on their first valves a variable negative grid bias, controlled by a *compactor* or, more properly speaking, a *compactor-expandor*. Amplifiers and compactor have been made possible by radio research of the past decade.

The exact arrangement of the radio equipment is always a closely guarded secret, though the general principles are known and applied in various modified forms by different companies. The hook-ups, valves used, etc., need not here be mentioned in detail. Indeed, in this case, they are not so known to the writer. It is quite sufficient for our present purposes to know that each galvanometer is provided with an individual amplifier unit and that their amplifications can be individually pre-set. The first valve of each set is controlled by the compactor, which is itself controlled by a thyratron which sets it in operation and a discharging condenser which controls it afterwards. The compactor puts a common negative bias on the grid of the first valve of each amplifier. The instant when it does this is determined by the arrival of the first ground energy at the most distant geophone, the sixth. That is to say, very shortly after the surface energy reaches the sixth geophone and the record begins, a thyratron valve is tripped. This valve places a negative bias on the grids of the first tubes of the amplifiers which, depending on the chosen value of this bias, may cut the amplification to zero or to any desired fraction of the full amplification chosen. This negative bias is removed by the discharge of a condenser. The rate of discharge of the condenser is set by suitable choice of a resistance.

Hence the volume or amplitude of swing of the galvanometers is not affected by amplification until the sixth geophone is operating. The amplification from that point forward is determined by pre-settings of dials which control:

(1) The time interval until the thyratron acts.
(2) The amount of inhibiting negative bias then introduced.
(3) The instant at which the bias begins to be removed.
(4) The rate at which the bias is removed.
(5) The final chosen amplification for each galvanometer.

The total energy may also be controlled by the amount and depth of the charge.

The entire recording equipment is housed in a special truck which is provided with light-tight doors. Each unit is readily removed for repairs or adjustment. A single amplifier unit is shown in Plate V, *I* and the right-hand bank of six amplifiers can be seen in Plate V, *K*. The truck illustrated is provided with twelve galvanometers, six on each side, though only six were used in the survey here described.

The truck is equipped also with developing and fixing apparatus and a gasoline stove which is used to bring the developing solution to the proper temperature in cold weather. Developing, fixing, washing, and drying of the records are all done immediately on location.

9. *Recording:* The hole having been completed, the recorder truck starts out along the surveyed line of the spread, trailing two cables from the hole, one for use as a telephone line and also to record the shot time; and the other, connected to an up-hole geophone left at the hole, for recording up-hole geophone time. At 200 feet a weathering geophone is placed in a hole about a foot deep, dug by means of a post hole auger. At 1,800′, 1,900′, 2,000′, 2,100′, 2,200′, and 2,300′ the six recording geophones are placed in similar holes. The cables from these six geophones are carried forward or back to connect with the terminals of the galvanometers on the outside of the recorder truck, placed between the third and fourth geophone at a distance of 2,050′ from the shot-hole.

It must be borne in mind that the distances used in a spread are chosen by the party chief and computer in the light of previous exper-

ience. The set of figures given here is simply one of many and is chosen so that an actual set of records may be discussed throughout all the computations.

All being in readiness, the recorder telephones the shooter to fire, say, 10 lbs. at 30 feet. When this charge is in place, all persons in the vicinity of the recorder truck are warned to stand still. The recorder then closes his dark room and telephones to the shooter. *"Ready! Contact! Shoot!"* The shooter thrusts down the plunger of the blaster, the charge is detonated, and the galvanometer light spots begin to record on the photographic paper, which the recorder set in rapid controlled motion at the instant he called *Contact.*

The recorder is able to see the movements of the light spots by means of prisms which deflect part of the light to a ground glass screen. When the movements cease—in about two seconds—the recorder removes the exposed strip of paper, plunges it into developer for a few seconds, then into water, next into fixer, and again into water. In about a minute all is complete and he opens the door to examine his record. He lays the paper strip on a board on which he has marked the reflections he wishes to record. He thus knows for what points on the record special care must be taken. If the reflections are not as good as required, the recorder decides on the change in variables which should "bring them up." He perhaps orders a different amount of dynamite at a different depth, sets his amplifier and compactor dials to new values and tries again. This continues for four or five shots until the required results are obtained or, perhaps, the hole caves.

Two of the shots, usually the first and the last, are special ones, designed to determine the thickness of the weathering and the velocity of elastic waves horizontally below it and vertically through it. These weathering shots are taken in various ways. We shall here discuss in detail *only one of them.*

The Wa shot is fired in the shot-hole and records are obtained of the up-hole geophone time and the first arrival times at each of the six galvanometers. On one of the other regular shots the geophone at 200 feet is connected in, in place of the up-hole geophone, and thus gives the time required for the waves to travel out to this geophone at 200 feet instead of directly up to the geophone at the hole. Finally,

the Wb shot is fired in the same hole which formerly housed the sixth geophone. Fig. 1 gives a diagram of the records obtained for the first Wa shot and for the final Wb shot. The Wb shot is shown in the upper of the two records and may be distinguished by the absence of movement for the sixth geophone, that instrument having been removed from its emplacement and disconnected in order to fire the Wb shot in its emplacement.

Again it is to be mentioned that this method of computing the weathering is not unique. It is desirable to follow through one method and apply the results by some one method. The weathering must be determined for each spread. The application of the results is the same in any case.

The weathering shots and satisfactory reflection shots having been obtained, the recorder so notifies the shooter and all hands prepare to move to the next spread. The cables are wound on the reels provided (see Plate IV, *L*) and the geophones gathered up. The shooter recovers his loading rods and his used cap wires. The recorder dries his records in readiness for a visit from the surveyor or the party chief. The hole is abandoned to fill up as nature wills. The activity of shooting and recording gives place, without loss of time, to that of dashing over the prairie to the next *set-up*.

10. *Scaling the Records:* On every record will be found the shot time impulse. The timing line immediately *after* this break is marked o and the number of thousandths of seconds before o that the shot time recorded is entered directly on the seismogram. It is called the *zero correction*. In Fig. 1 it will be noted that the zero correction for the upper (Wb) record is 6-thousandths and that the correction for the lower (Wa) is zero. Choosing the timing line *after* the time break insures that the zero correction will always be *positive*. This correction is added to the readings as first determined. On the appropriate seismogram in each case the time intervals are scaled and recorded on the record itself, the following time values being thus obtained:

(a) the up-hole geophone time.
(b) the 200′ geophone time.
(c) the first arrival times for the Wa shot.

(d) the various reflections recorded.
(e) the first arrival times for the Wb shot.

The exact beginning of all of these, except the reflections, is easily determined. The reflections are more difficult to detect and time. Usually, the computer takes as the arrival time of a reflection the first of the sharp peaks. (See Fig. 5.)

The records having been scaled, it is now necessary to compute the weathering correction. This, when evaluated, together with the correction to reduce all to a chosen datum plane, must be applied to the reflection times as read from the seismograms. The values will be further modified by applying a *spread correction* to be described later. This reduces the time interval to that required for the elastic waves to travel vertically upward from the reflecting horizon to the datum plane. Then, the average vertical velocity having been determined for the area by some method (three will later be briefly described), the depth of the reflecting layer below the datum may be computed. The surveyor has already determined the elevation of the point on the surface immediately above the corresponding point at which reflection took place on the reflecting horizon. Thus we know how far the surface point is above the datum and how far the reflecting point is below it. The sum is the depth to the reflecting point. In plotting depth values to obtain contours, only the depth below datum is used. The surface-to-datum depth is useful only for that point at which a well is to be drilled.

II. *Theoretical Wave Paths:* In reducing the records, for the case of horizontal parallel horizons we are here considering, the wave paths are assumed to be very simple. *In reality they certainly are not*, but the errors introduced by the assumptions made are not serious. They tend to slightly lift or lower all the depth determinations by about the same amount. It has been found by experience that it is better to use the simplified assumptions and thus cover territory more rapidly, the field computations being greatly reduced thereby.

Referring to Fig. 3, we assume that the energy in the weathering determinations follows the rectangular paths shown. That is to say, the energy which reaches say geophone 3 in the Wa shot, travels from

the shot at S down to A, across to E and up to 3; while that reaching the same geophone from the Wb shot travels from the emplacement at 6 to H to E to 3.

Thus the successive first arrival times will differ by the times required for the energy to travel horizontally along the line AH by that the weathering at the shot hole is less than at the geophones. It is not unusual for these to differ. We shall see in the next paragraph about .01 sec. It will be seen on reference to Fig. 1 that this is the case.

The reflections may here be supposed to travel in straight lines as indicated in Fig. 4. The differences in arrival times for the reflections will be measured by the differences in path for successive geophones, as for example, SA1 and SB2, divided by the average vertical velocity—in Alberta about 11,500 ft./sec. The differences in path are small and the velocity is high. Thus the differences in successive arrival times for a reflection are less than for the near surface paths.

Hence, if a line be drawn through successive first arrivals on a record and another line be drawn through successive reflections from a common horizon, the former line will be much more inclined to the axis of the record than is the latter. Reference to Fig. 5 will give good examples of this.

12. *Computing the Weathering:* Referring to Fig. 1 and Fig. 3 let us compute the weathering as follows:

(a) We write down the successive arrival times for Wa (the lower record of Fig. 1) and under them write the successive arrival times for Wb (the upper record of Fig. 1). These are added, diminished by the arrival time at the sixth geophone of Wa, and the remainders divided by 2. Thus we have:

Wa	.181	.189	.199	.207	.219	.225
Wb	.083	.071	.061	.050	.036	
Wa+Wb	.264	.260	.260	.257	.255	
−Wa6	.225	.225	.225	.225	.225	
2t	.039	.035	.035	.032	.030	
t	.0195	.0175	.0175	.016	.015	

Let us see what these values t denote. Consider the figures applying to, say, geophone 3.

.199	=	time	to	travel	path	SAE3
.061	=	"	"	"	"	6HE3
.260	=	"	"	"	"	SAH6+2·E3
.225	=	"	"	"	"	SAH6
.035	=	"	"	"	"	2·E3
t = .0175	=	"	"	"	"	E3

In like manner, .0195 sec. = time to travel path C1 and so on. If the weathering were uniform these should all be equal. Evidently they vary from .0195 down to .015. There is a difference between the least and the greatest of .0045 sec. If they are averaged the value will give the average vertical velocity through the weathering and this average will not differ by more than about .002 sec. from any individual value.

(b) Let us now obtain the successive values Wa-t which are as follows:

.1615 .1715 .1815 .191 .204

These are the successive time intervals required for the energy to travel the paths

SAC, SAD, SAE, SAF, SAG.

If we plot these points to scale the slope of the line through them will give the velocity of the elastic waves along the line AH. Examining the first three, we see they differ successively by .01 sec., which represents travel of 100′ and hence the horizontal velocity in the sub-weathering is, as we have said, about 10,000 ft/sec. This plotting is always done; for a velocity nearly this great must be obtained or the energy did not penetrate the weathered layer. It is usual also to plot the Wa arrival times which should, by the same reasoning, yield a slope nearly the same. If the points do not lie approximately in line for both plottings, or if the slopes indicate horizontal velocities too small, it is concluded that the shot did not penetrate the weathering and the record is abandoned.

(c) Referring to Fig. 1 we see the interval from the shot time to the up-hole time was .01 sec. This shot happens to have been fired

at a depth of 30 feet. Thus the up-hole velocity is roughly 30/.01 = 3000 ft/sec. The average of the five values of t is evidently .017 sec. This is the vertical time under the geophones. Assuming the vertical velocity at the shot hole to be about that at the geophones—3000 ft/sec.—we find the thickness of the weathering to be 3000 x .017 = 51′. But the geophones were buried a foot deep, so the weathering is to be taken as 52′.

(d) It is desirable to determine whether the shot was below the weathering. To do this we use the up-hole geophone time and the time to the 200′ geophone. The latter was in this case .026 sec. This is not shown on the records reproduced but was recorded on one of the others made in the spread concerned. Referring again to Fig. 3 we find the times for the following paths are: SU = .010 sec., as noted in (c) above; SABG = .026 sec.; whence UABG = .036 sec.

Now the distance AB = 200′, and the horizontal velocity in this line is found to be 10,000 ft/sec., so the elapsed time for the path AB = .020 sec. Subtracting this from the value for the path UABG, we get the paths AU + BG = .036 – .020 = .016 sec. or AU = .008 sec., assuming the vertical velocities to be the same at the shot hole and at the 200′ geophone. At 3000 ft/sec. this gives the weathering at the shot hole to be 3000 × .008 = 24′. The shot was fired at a depth of 30′.

Note that the computation shows the path followed to the 200′ geophone was *not* down, across, and up as tentatively drawn in Fig. 3; for the up-hole-time (.01 sec.) is more than the computed average for AU (.008 sec.). However, the procedure is sufficient to show that the weathering is less than the shot depth (30′) and that is the only result required or used. Had it not been so, we should have had to correct for that part of the travel time below the shot which traversed the weathering at the low velocity of 3000 ft/sec. Note too steps of 100′—the distances from C to D, etc. As this velocity in Alberta is about 10,000 ft./sec. the successive arrivals will differ by that the surface elevations differ by more than 40′, another fact not taken account of in the schematic drawing.

(e) We next refer to the surveyors' values for the elevations of shot hole and the six main geophones. The former was found to be

3,239′ above sea level and the average of the others 3,281′. The average of these we denote by the symbol Em = the elevation of the mean, where:

$$\text{Em} = 3{,}260'.$$

From now on we consider only one geophone and assume it to be the third. The arrival times for a single reflection as registered on all five geophones are averaged and considered to be that for the third geophone.

Consider now Fig. 6 where conditions have been drawn to scale. Evidently Em = ML = 3,260′.

The shot depth for this case happens to be 30′. The weathering depth was found to be 52′ at the geophones. The average of these is 41′ and, referring to Fig. 6 this is evidently the length FM. We denote it by W.

Then the distance of F above the datum plane is evidently

$$\begin{aligned}\text{Em} - \text{W} - 3{,}000' &= 3{,}260' - 41' - 3{,}000' \\ &= 219' = \text{FB}\end{aligned}$$

We may take, approximately, that

$$\begin{aligned}\text{SC} + \text{AD} &= 2 \times \text{FB} \\ &= 2 \times 219' \\ &= 438'\end{aligned}$$

If we take the average vertical velocity from R to F to be 11,500 ft/sec. the time required for the energy to travel the parts of paths SC + AD will be

$$438/11{,}500 = .038 \text{ sec.}$$

Thus the correction for time in the weathering = .017 sec. and the correction for time below the weathering and above the datum = .038 sec. The total correction to datum is thus .017 + .038 = .055 sec.

(f) The time for the impulse to travel from the shot to the reflecting horizon considered and up to the geophones was found when averaged for geophone No. 3 to be 1.065 sec. Subtracting .055 sec. we have 1.010 sec. for the time over the path CRD. This must now be reduced to give the distance BR.

This reduction could be done as follows: Consider the paths rectilinear and take the distance CD as equal to UG = 2,000′. Taking the average vertical velocity as 11,500 ft/sec., the elapsed

time 1.010 sec. indicates that the distance CRD = 11,615′, and hence RD = 5,807′. But BD = 1,000′. Hence, solving the right-angled triangle, BR = 5,719′.

(g) The above is not the usual field method of reduction. As stated earlier in this report, the correction for the path below the datum takes into account the slightly warped paths for the rays from S to R and from R to A. The correction is read from a nomograph computed for the geological conditions of the region, which one enters with the spread width and the average vertical velocity. The time to go from S to G was found to be 1.065 sec. That from AG was found to be .017 sec. Hence the time over path SRA = 1.065 – .017 = 1.048 sec. The *spread correction* given by the nomograph is –.014 sec. and serves to change the elapsed time to that required to go from F to R to F or, in time, 2FR = 1.034 sec.

whence, in time, FR = .517 sec.

This is travelled at the rate 11,500 ft/sec.; whence the value, in distance, is FR = 5,946′. To compare this value obtained by nomograph with that obtained in (f) above by solving the triangle, we subtract the distance FB = 219′, obtaining 5,727′ by nomograph and 5,719′ by solving the triangle. If we take the nomograph result as the more correct (and it should be, as is evident on consideration of the assumptions made in the triangle method) then the distance

$$\begin{aligned} \text{FR} &= 5{,}946' \\ \text{FM} &= \quad 41' \\ \text{MR} &= 5{,}987' \\ \text{ML} = \text{Em} &= 3{,}260' \\ \text{LR} &= -2{,}727' \end{aligned}$$

= elevation referred to sea-level, of the reflecting point R on the reflecting horizon concerned.

In plotting depth values for a contour map of this horizon we may take them in feet with respect either to sea-level datum or to the 3,000′ datum; or we may use the reduced time values for the distance BR or even its double value. If the entries are consistent, the presence of a structure will be indicated.

In practice, all the above computations are done on specially printed forms. The work becomes a routine which may be readily

checked. As a rule two men collaborate in the computing, each checking the original computations done by the other.

13. *The Contour Map*: The entire *raison d'être* of a seismic survey is the production of an accurate contour map of one or more horizons, showing definite evidence of a *structure*. A great deal of experience is necessary to enable the geophysicist to draw contours among the plotted depth values. He must be a good geologist as well as a geophysicist. He must know the relative weights of his depth determinations. That is to say, he must know the difficulties experienced by the driller, the shooter, the recorder, and the computer.

A sample of a contour map is shown in Fig. 7. It is to be noted that *this does not represent conditions for any field*. It was constructed with some care to show the nature of the problem but the picture is a composite one. In field practice it is sometimes necessary to do a good deal of profile work before a structure is located. Thus vertical velocity times are usually not calculated until the need arises. Till then the contours are based on the corrected times determined for the elastic waves to travel vertically upward from the reflecting layer to the datum plane.

14. *Determining Average Vertical Velocity*: Several methods may be used for this purpose. We shall indicate briefly three of these.

(a) *Refraction Shooting*: In this method a location is chosen where the line of the spread is as level as possible and where it may reasonably be supposed that the successive horizons are level and hence parallel along the same line projected down upon them. Then successive charges of dynamite are fired at the same hole and the recording equipment is moved outward step by step, the first recording being done at say 100′, 200′, 300′, 400′, 500′, and 600′ from the shot, the next at 700′, 800′, 900′, 1,000′, 1,100′, and 1,200′ and so on, carrying the recording out to a mile or even two miles and using successively heavier charges as the work proceeds. Plotting the arrival times, and assuming for illustration that there are three layers of differing thickness and each with its own unique horizontal and vertical velocities, we get a diagram something like that shown in Fig. 8. It will be observed that the plotted points define three straight lines and that the intersections of these three lines may be

found. It is possible with these data to determine the horizontal velocity in each layer and the average vertical velocity from each discontinuity. This method is tedious and requires the use of very heavy charges of dynamite for the more distant recording. It is seldom used on that account.

(b) *Reflection Shooting*: A series of reflection shots are made after much the same plan as above but to lesser distances and, since reflections only are required, using smaller charges. The records are corrected for weathering and reduced to datum as before. Then, following the method of section 12(f), any two of these records are reduced to evaluate the depth from datum to reflecting horizon using a series of average vertical velocities for the computations.

For example, in such an investigation in Alberta the values for depth for the stations at 1,000′ and 3,400′ respectively, assuming 10,000 ft/sec. were respectively 5,412′ and 5,351′. Obviously, if the average velocity chosen had been correct they should have been equal. Subtracting the former from the latter and denoting the difference by D we get D = –61′, when the average vertical velocity was taken as 10,000 ft/sec. Repeating, and using a velocity of 11,000 ft/sec. the difference was found to be –26′. Repeating and using a velocity of 12,000 ft/sec. the difference was found to be + 12′. Plotting these differences on coordinate paper with the ordinates representing the differences and the abscissae representing the assumed vertical velocities, the three points were found to lie on a straight line which cut the axis of abscissae at a point indicating a velocity of 11,670 ft/sec. This was the value of the average velocity indicated, the value of D being zero.

This value could be checked by taking other pairs of values and if agreement was good taking an average. Note that it yields average velocities from some chosen horizon whose actual depth is not known until the average velocity is known, both emerging from the same calculation. If the values prove discordant, we must assume that our premises have not been met. The strata were not horizontal and parallel. By shooting in the opposite direction and across the line first chosen corrections could be determined to make the results concordant but it is a slow and therefore costly process.

(c) *Shooting a Logged Well*: The best method and also the cheapest is to shoot a reflection spread over a well whose log is known. The depth and nature of the reflecting horizons and their relative order permit the assigning of definite interpretations to successive reflections on the records. Reversing the calculation processes of Section 12 the known depths may be used to reduce the observed data of elapsed times to average velocities for the various depths.

15. *Conclusion*: In conclusion, it is to be stated that the object of this report is to present a complete but simple picture of the routine procedure in conducting a seismic survey. It is to be repeated that all complicating phases have been avoided, that in addition to the procedure outlined the same company would use alternative methods in particular cases, that other companies using other equipment would use slightly different methods, and, finally, that any company operating in other geological structure would use still other modifications. It is hoped that this outline of one complete procedure will serve to acquaint those who wish only a general idea of the method with the difficulties to be met and with the possibilities of the reflection method of seismic prospecting.

Department of Mines and Resources,
Dominion Observatory,
January 30, 1939.

NUCLEAR DISINTEGRATION*

By Elizabeth J. Allin

FOR some years now we have been accustomed to think of the atom as an open structure resembling somewhat a miniature solar system. The atom has a diameter of the order of 10^{-8} cm. but practically all of its mass, according to this conception, is concentrated in a nucleus which has a diameter of only about 10^{-12} cm. This nucleus bears a positive charge which is just balanced by the sum of the negative charges on the electrons which describe orbits about it under the influence of its electrostatic attraction, much as the planets describe orbits about the sun under the influence of its gravitational attraction. It was early discovered that similarities in chemical properties could be accounted for if atoms with similar extra-nuclear electronic structures had similar chemical properties and so it was concluded that such properties were determined by the nuclear charge. The two important characteristics associated with any nucleus are then its charge and its mass and if these two are given it is believed to be uniquely defined.

When the nuclear atom was first proposed it was not evident whether the nucleus should be considered as a simple more or less homogeneous mass particle of very great density or whether it should be regarded as composed of a number of particles of still smaller size in close association with one another. The earliest information on this point was provided by the discovery of radioactivity. When in 1896 it was found that certain elements spontaneously emit corpuscular radiations these were attributed to the sudden breaking up of the atoms of those elements and the ejected particles were looked upon, accordingly, as having existed initially as units in the structure of the disintegrating atoms. Unlike chemical changes these radioactive processes were unaffected by external physical conditions such as temperature and pressure. It was therefore concluded that, whereas the extra-nuclear part of the atom determined its chemical behaviour, the nucleus was

*A lecture before the Toronto Centre of the R.A.S.C.

Dr. Allin is a Lecturer in Physics in the University of Toronto.

responsible for radioactive emission. Two kinds of particle were given out, the α-particle and the electron. It appeared to follow from this that these formed two constituents of at least the heavy radioactive nuclei.

Only a few of the heavy elements are radioactive. In order to gain knowledge of the components of the nuclei of stable atoms Lord Rutherford in 1919 conceived the idea of bombarding them with beams of the high speed α-particles emitted by a radioactive material, in the hope of producing artificially disintegrations of the same type as those occurring naturally in the case of unstable nuclei. The α-particle, being in fact the nucleus of a helium atom, is of nuclear dimensions and hence will pass freely through the external part of the atom. If, however, it happens to be directed at the nucleus it will impinge on it provided it has enough energy to overcome the electrostatic repulsion, and may cause it to disintegrate. When the experiment was first performed nitrogen was used as the target material and it was found that some of the atoms were indeed broken up since protons or hydrogen nuclei were observed to come from the nitrogen although no hydrogen was originally present. Since that time hundreds of such experiments have been carried out and it is largely to these that we look still for information regarding the nucleus.

In the beginning the α-rays from radioactive sources were used for projectiles as in the case cited above and, owing to the small amount of radioactive materials available, the number of particles in the beam was subject to serious limitation. Now it has been noted that by far the greatest part of the atom is empty and in general the α-particles will pass through this empty space and not come close enough to a nucleus to collide with it. Since the probability of an α-particle being aimed directly at a nucleus is very small there must be a large number of them in the beam if they are to bring about sufficient disintegrations to make possible the observation of the products. Accordingly any such restriction on the size of the source is undesirable as is also the inability of the investigator to vary at will the energy of his projectiles. Owing to these difficulties much effort has been expended on the development of sources of high potential which may be used to accelerate ions to high energies and since 1930 progress in this field has been

very rapid. The fastest α-particles from radioactive atoms have energies of 8 to 9 million electron volts (i.e. an energy equal to that acquired by an electron in falling through a potential of 8 to 9 million volts). Lawrence and his colleagues in California have been successful in accelerating helium nuclei to an energy of twelve

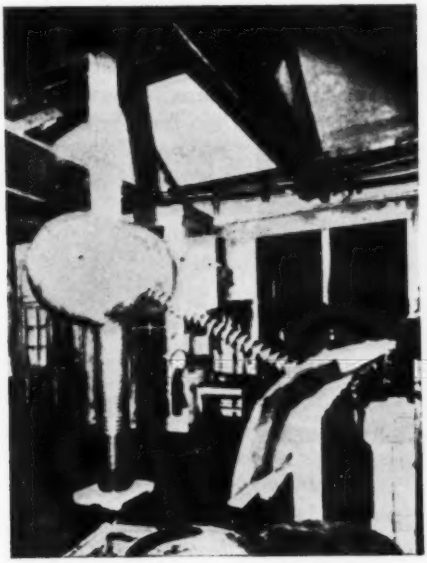
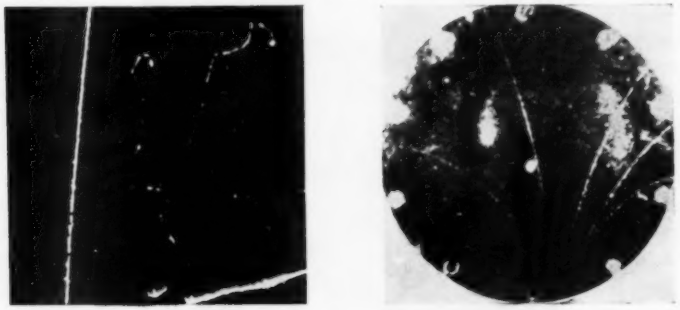


Fig. 1.—Electrostatic generator and cascade tube used at the Department of Terrestrial Magnetism at Washington to study the disintegration of lithium and boron.

million electron volts and the beam intensity available is thousands of times greater than that from most natural α-particle sources. Comparable results have been obtained in other laboratories. Furthermore one is no longer limited to a single type of projectile, the α-particle, but any ion can be utilized in the same way. Accelerating voltages as high as those mentioned above are not absolutely necessary since it is found that disintegrations may

occur even though the incident particle has relatively small energy. The probability of its occurrence decreases with the energy of the projectile and so if high voltages are not available correspondingly stronger beams must be used to achieve similar results.

Several methods are used for the detection and identification of the products of disintegration. These latter are usually two in number, one a light nucleus travelling with high velocity and often spoken of as the ejected particle, the other a heavy nucleus whose velocity of recoil is fairly small. The earliest method of detecting the ejected particle was the fluorescent screen. Each particle



A B

Fig. 2.

(a) α and β tracks showing the difference in ionising power of the particles.
(b) Tracks of positrons and electrons showing opposite curvature in a magnetic field.

impinging on a zinc sulphide screen produces a flash of light and these individual flashes may be observed by means of a microscope. The range of the particles may be determined and their energy deduced from the energy-range relation known to hold for the type of particle concerned. This method has been now largely superseded by electrical counters and the Wilson cloud chamber. In the former the particles enter a small ionisation chamber so arranged that their entrance causes a sudden instantaneous increase in the current passing through it. This pulse is amplified and registered either by a loud speaker or on a recording drum. It is

possible to distinguish between particles which have different specific ionisations since those of greater ionising power will produce a larger pulse. The range of the particles may be measured and their energy estimated as before.

In the Wilson cloud chamber the particle passes through a vessel containing gas saturated with water or alcohol vapour and the ions produced by it along its path act as nuclei for the condensation of the vapour when the gas is cooled by sudden expansion, thus making the path visible. A particle which produces intense ionisation will give rise to a much denser track than one of smaller ionising power and the nature of the particle may be determined from the appearance of the track. A positively charged particle may be distinguished from a similar one of negative charge by applying a magnetic field to the chamber since they will then be deflected in opposite directions. Stereoscopic photographs make it possible to determine both the direction of the tracks in space and the range of the particles.

The cloud chamber may also be used to observe tracks due to the recoil nuclei particularly if the pressure of the gas in it is reduced well below atmospheric. In certain favoured cases the identity of the recoil nucleus can also be ascertained by chemical methods but in many of the early experiments its nature was not determined directly but was deduced on the assumption that mass and charge were conserved in the collision.

The following table lists all of the high-speed products of both radioactive and collision disintegration processes which have been observed up to the present time.

Product	Approx. mass Oxygen = 16	Charge e = charge on electron
Proton or hydrogen nucleus	1	$+e$
Deuteron or heavy hydrogen nucleus .	2	$+e$
α-particle or helium nucleus	4	$+2e$
Neutron	1	0
Electron	1/2000	$-e$
Positron	1/2000	$+e$
Photon or γ-rays	—	—

Certain observations made a year or so ago led to the announcement of the discovery of a new particle, the heavy electron or barytron, having a mass several hundred times that of the electron but the same charge. More recent investigations have failed to establish its emission in disintegration processes.

The neutrino, a particle of vanishingly small rest mass and uncharged, is also introduced in certain theoretical work. Such a particle is not susceptible to observation by direct experimental methods.

What has been said would lead to a nucleus composed of some or all of the particles in the above table. While our ideas of the nucleus are still rather indefinite the present view is that it is made up fundamentally of neutrons and protons. The two essential properties of a nucleus are, as mentioned earlier, its mass and its charge. By suitable combinations of neutrons and protons a nucleus of any desired mass associated with any desired charge may be constructed. The following table shows how, on this basis, the nuclei of ten atoms at the beginning of the periodic table would be built up:

Element	Approx. mass Oxygen = 16	Charge e = chge. on electron	No. protons	No. neutrons
Hydrogen . .	1	1	1	0
" . .	2	1	1	1
" . .	3	1	1	2
Helium . . .	4	2	2	2
Lithium . . .	6	3	3	3
" . . .	7	3	3	4
Beryllium . .	9	4	4	5
Boron . . .	10	5	5	5
" . . .	11	5	5	6
Carbon . . .	12	6	6	6

If nuclei are composed solely of neutrons and protons how can particles other than these be emitted in nuclear disintegrations? This is now supposed to occur in the following way: if at any instant it were possible to see inside the nucleus, in the midst of the general assemblage of protons and neutrons would be seen,

here and there, groups of two protons and two neutrons more closely bound together than the general run. An instant later these particular groups would have dissolved and others would have been formed elsewhere. If such a group happened to be formed on the surface and if at the moment of formation it happened to accumulate sufficient energy it would escape and appear as α-particle emission. It can scarcely be regarded, however, as having existence previous to the moment of its ejection. Only a single case is known in which deuterons are ejected and this must be looked upon as taking place in much the same way.

Positrons and electrons are never observed directly as the result of a bombardment but only as products of the spontaneous disintegration of unstable nuclei. Such particles are regarded as being created at the moment of disintegration owing to the transformation of a neutron into a proton in the case of the electron, or of a proton into a neutron in the case of the positron. There is no conclusive evidence against their existence as such in the nucleus but their presence there creates difficulties in the theory which we as yet do not know how to overcome. It may be that the results of future experiments will force us to change our views and to include them in the same way as the heavy particles.

Detailed attempts at forming nuclear theories have met with but limited success since little experimental data is available concerning the forces which hold the nucleus together. Results obtained recently from the scattering of protons by protons and of neutrons by protons indicate however that the forces between like and unlike particles in the nucleus are at least of the same order of magnitude.

Owing to the open character of the atom, bombarding particles may pass through it without interaction. This is not true of the nucleus which although ten thousand times smaller embraces almost the whole mass of the atom. The particles in it surely must be very closely packed. A particle falling on it, therefore, cannot possibly pass through it without interacting with those already there and will lose part of its energy as soon as it strikes the surface. As it goes on there will be further dissipation of energy among the nuclear particles and as a result the energy which was originally concentrated on the incident particle will

become distributed over all the nuclear particles as well. These being in close contact, this energy distribution will change continuously and after a time, actually very short, a state may again be reached in which most of the energy is concentrated on a single particle, the original or some other, and this may escape. In this discussion only those collisions are of interest in which the particle finally escaping is of a character different from the incident particle.

The α-particle, the proton, the neutron, the deuteron and γ-rays in addition to appearing as products in some disintegrations have been used successfully as projectiles in inducing others, and altogether several hundred cases have now been observed. The method used to represent individual disintegration processes is typified by

$$N_7^{14} + H_2^4 \rightarrow O_8^{17} + H_1^1$$

which indicates that the nitrogen nucleus when bombarded by an α-particle ejects a proton and forms the nucleus of O^{17}, an isotope of oxygen of mass 17. The number to the upper right of the chemical symbol gives the mass of the nucleus, that to the lower right its charge.

In the earlier work the new nuclei formed showed no signs of instability and were in general isotopes already known to exist from work with the mass spectrograph. Thus, for example, the bombardment of nitrogen by the α-particles from RaC^1 produced oxygen of weight 17, known to exist in nature in small quantities. Fluorine under similar bombardment produced the known isotope Ne^{22}, etc. Artificially accelerated protons and deuterons and beams of neutrons also in many cases formed stable nuclei. Such is, however, by no means always true. In 1934 Curie and Joliot reported that they had observed delayed positron emission from boron, magnesium, and aluminium after these had been bombarded by α-particles. The intensity of the emission was found to decay exponentially as does the activity of naturally radioactive substances. Chemical tests were performed in each case to determine the active element. In the first case it was nitrogen, in the second silicon and in the third phosphorus. Since that time a great many instances of "induced radioactivity" have been observed, the radiation consisting sometimes of positrons and sometimes of

electrons. We now know at least three kinds of radioactive sodium, three of radioactive aluminium, four of radioactive copper, etc. The same radioactive isotope may be produced by several different disintegration processes but no matter what its origin it will decay in exactly the same way. For example, Na^{24} results from five reactions but in each case it decays with electron emission at such a rate that half of its atoms have broken up in 14.8 hours.

Where radioactive substances are produced it is particularly simple to perform chemical tests to identify the recoil nucleus. To the active material is added a quantity of an inactive element of which the active one might possibly be an isotope. This element is then separated out again by standard chemical methods and tested for activity. This procedure is repeated for a series of elements until that responsible for the activity is ascertained. In the case of non-radioactive products chemical tests are difficult since the work must be done with the small amount of material created in the disintegration.

In any nuclear process charge, mass number, energy, and momentum are conserved. Mass and energy must be regarded, however, as equivalent quantities and possible transformations of one into the other must be admitted. In the early work the masses of the recoil nuclei calculated on this assumption were compared with those obtained with the mass spectrograph in order to see whether this assumption of exact conservation were justified. Now such masses may be regarded as checks on the mass spectrograph determinations and errors in the latter have been shown up in this way and later corrected. A means is also provided for the evaluation of the masses of radioactive nuclei having a short life and of nuclei which although stable are so rare that measurement with the mass spectrograph is impossible.

In some processes it is found that energy is actually converted into mass, i.e., the combined weight of the products is greater than the sum of that of the incident particle and that of the target nucleus. For example, consider the reaction $N_7^{14}+He_2^4 \rightarrow O_8^{17}+H_1^1$. The accurate value of the mass of N^{14} is 14.007, of He^4 4.004, of O^{17} 17.004, and of H^1 1.008. Thus the α-particle and the target nucleus together give a total mass of 18.011, whereas the recoil nucleus and proton give 18.012. Accordingly the energy of the

recoil nucleus added to that of the proton must be less than that of the incident α-particle and experimentally this is found to be so. In by far the greatest number of disintegrations, however, the converse is true—energy is evolved in the process. Let $Li_3^7 + H_1^1 \rightarrow 2He_2^4$ be taken as an example. The exact mass of Li_3^7 is 7.018 so that the total on the left hand side is 8.026 and on the right hand side 8.008. The difference of .018 mass units corresponds to an energy evolution of 17.25 million electron volts. Measurements of the energy of the emitted α-particles confirm this estimate.

It is now thought that the energy liberation in stars is due to thermo-nuclear reactions, i.e., to nuclear transformations caused by violent thermal collisions at the very high temperatures existing in the interior of a star. According to Bethe the important reactions in ordinary stars are the following: C^{12} is bombarded by a proton yielding N^{13} which is radioactive and breaks up with the emission of a positron giving C^{13}. This in turn on being struck by a high speed proton forms N^{14} which in its turn, again due to proton bombardment, gives O^{15} which is radioactive and emits a positron in going over into N^{15}. Finally the N^{15} in collision with another high speed proton is converted into $C^{12} + He^4$. In symbolic form this series of processes would be written:

$$C_6^{12} + H_1^1 \rightarrow N_7^{13} \rightarrow C_6^{13} + e^+$$
$$C_6^{13} + H_1^1 \rightarrow N_7^{14}$$
$$N_7^{14} + H_1^1 \rightarrow O_8^{15} \rightarrow N_7^{15} + e^+$$
$$N_7^{15} + H_1^1 \rightarrow C_6^{12} + He_2^4$$

The net result is that four protons have disappeared and one helium nucleus has been formed, the nitrogen and carbon entering into the series having remained unchanged in quantity. Thus on this basis the hydrogen would be gradually changed into helium and the heavier elements would remain unchanged in abundance. Calculations show the energy released in these processes to be of the same order of magnitude as that given by observational data.

In conclusion, attention is drawn to a new type of nuclear disintegration recently reported. Whereas in the cases discussed above the products were always of very unequal mass, observations made on the disintegration of uranium lead to the conclusion that

in this case two almost equal nuclei are formed. Previously the bombardment of uranium by slow neutrons has been supposed to give rise to an isotope of radium, but seeking to detect the radium chemically Dr. Hahn found only barium. Now uranium has a nuclear charge of 92 and known isotopes of mass 235 and 238 while barium has a nuclear charge of 56 and known isotopes ranging in mass from 130 to 138.

$$Ur_{92} + n_0^1 \rightarrow Ba_{56} + ?$$

The second product remains as yet unidentified but the interesting feature is that it must be a nucleus of mass comparable with that of barium. The energy evolved in the process is much greater than that due to the type of reaction treated in the earlier part of the paper, being at least one hundred million electron volts.

Department of Physics,
University of Toronto.

METEOR NEWS

Observations relating to meteors and meteorites are cordially invited.

Observations of the Orionid and Geminid Meteors, 1938

As mentioned last month generally cloudy weather was experienced in Ontario near the maxima of all the fall meteor showers. The group at the Ottawa Observatory, however, had one good night for observing the Leonid shower and the report of this programme will appear in a future issue of the JOURNAL. In addition to this Jack Grant, in Orillia, carried out photographic observations of the Orionids and Geminids on several nights that were broken by clouds and the Geminid shower was observed on one partly cloudy night at the Dunlap Observatory. The results of these programmes were very meagre owing to the poor weather.

Table I—Visual Observations

Station	Date	E.S.T.	Total minutes observed	Meteors O	Meteors N	Hourly Rates (one observer)		Weather Factor
Orillia....	Oct. 3– 4	4.38— 4.58	14	3	2	12	8	8
"	18–19	11.40— 0.23	21.2	0	*1	0	3	10
"	21–22	4.17— 5.23	33	9	2	16	4	4
				G				
D.D.O....	Dec. 12–13	9.00—10.00	60	15	3	11	2	9
" ...		10.00—11.10		9	0			4

Bright meteors observed during photography at Orillia—15.

Magnitude Distribution at D.D.O.

Mag.....	0	1	2	3	4	5	Totals	Mean Mag.
Geminids.....	2	2	5	4	6	5	24	3.0
Non-Geminids.....		1		1		1	3	3.0

*Telescopic meteor of 7th mag. in Orion, nebulous and swift, observed with prism binoculars 1.2 inches aperture, 8×, field 6°.9, efficiency 42.

The visual results are given in Table I. The writer was assisted at the Dunlap Observatory by Mr. G. H. Tidy of the observatory staff. Owing to the short intervals of clear weather the rates listed are not very reliable. No very bright meteors were seen at the Dunlap Observatory. Mr. Grant reported a number, seen while he was operating his cameras.

The results of the photographic programme are summarized in Table II. Two Geminids were photographed, one at Orillia and one at the Dunlap Observatory. The latter was taken through a

TABLE II—PHOTOGRAPHIC OBSERVATIONS

Station	Date	Total Exposure Time	Meteors Photographed	Weather Factor	Cameras
Spectrophotography					
D.D.O.	Dec. 12–13	5.0 hrs	—	7	F/4.5, F/4.5
Direct Photography					
Orillia	Oct. 3– 4	0.4	—	10	F/1.9
"	" 20–21	0.7	—	2	F/6.3, F/8.0
"	" 21–22	8.4	—	4	F/1.9, F/6.3, F/8.0
"	Dec. 12–13	4.6	1	8	F/6.3, F/8.0
D.D.O.	" 12–13	2.5	1	7	F/2.

rotating shutter. Although co-operation had been planned between the two photographic stations unfortunately the periods of clear sky at each did not coincide and so no meteor was doubly photographed.

Any reader of the JOURNAL who has a camera, and could observe the Perseids this summer at some point 20 to 30 miles from the Dunlap Observatory, is in a position to render a real service to Canadian astronomy. The writer will be glad to hear from anyone who would like to volunteer.

P. M. M.

REVIEW OF PUBLICATIONS

Variable Stars, by Cecilia Payne-Gaposchkin and Sergei Gaposchkin. (Harvard Observatory Monograph, No. 5.) 6 × 9 ins. Cambridge, Mass., Harvard Observatory, 1938. Price $3.25.

The study of variable stars has spectacularly advanced during the twentieth century, both in the cumbersomely large number and variety of variables, and in the extent of the bibliography of the subject. The authors of Variable Stars express the hope that "the astronomer may find in it some help in orienting himself among the variables, which are appearing so fast that they bid fair to envelop him like a thickly growing forest, through which it will soon be too late to cut a path". Readers will feel that the authors serve as skillful foresters, who not only blaze definite trails, but at the same time furnish much accurate information as to the stand of timber in this forest.

In this book all the various characteristics of variables of different kinds are described minutely, catalogued, and intercompared, and tabulated for individual stars. About one-third of the whole book is made up of dozens of such tables. The index of individual variables at the end of the book contains references—in some cases very numerous—to about eighteen hundred different variable stars.

The classification used consists of four major divisions, as follows:

A *Geometrical Variables*	B *The Great Sequence*	C *Cataclysmic Variables*	D *Nebular Variables*
Eclipsing stars	Long period v.	Novae	
Ellipsoidal stars	Semi-regular v.	SS Cygni stars	
Obscured stars	Cepheid variables	R Cor Bor stars	
	Cluster type v.		
	Irregular red v.		

Four sections of the book deal with these four classes, and another very important section with the discovery and photographic study of variables.

The seventy-five pages dealing with geometrical variables discuss the nature of these stars, and the observational material, and conclude

with excellent tables giving the relative orbital elements of 270, and the spectroscopic elements of 62 eclipsing binaries. The longest and most diversified section is, of course, that dealing with the Great Sequence. The general elements and numerical data describing the curves of 320 long period variables are given. Selected lists of galactic cepheids, of galactic cluster type, β Canis Majoris variables, and irregular variables are included. The chief tables in the section on cataclysmic variables include all galactic novae of the past century, and a summary of ordinary extragalactic novae, supernovae and the SS Cygni and R Corona Borealis type stars. The section on extrinsic variables includes variable stars in nebulosity, nebular variables, associated irregular variables, and spectrum variables.

Many astronomers will find these extensive tables indispensable. And quite apart from these tables, the text of the book is written in such an interesting and informative style that it will serve as a reference work for students and intelligent amateurs. The substitution of a detailed table of contents for an alphabetical index is justifiable though an index would be useful to many readers.

There has been a long and widely felt need for an encyclopaedic book of this kind about variable stars. The Harvard Observatory, with its variable star tradition, was the logical sponsor of such a book, and the Gaposchkins have produced a book which admirably fills this need.

F.S.H.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

The Bright Aurora of February 24, 1939

An unusually brilliant auroral display was observed on the night of Feb. 24, 1939, at the observatory at Richmond Hill. It was first noticed at 7.00 E.S.T. despite moonlight and twilight. The following descriptive notes were made at the time:

7.00 Red and green rays arising from a narrow region on the horizon due east extending to about 20° altitude with a thin band extending overhead and nearly to western horizon (note: western horizon bright with twilight).

7.05 Rays less distinct in east—red not so noticeable but still present. More overhead with a distinct corona centred at β Aurigae (note: until 7.15 work with telescope had prevented examining northern horizon).

7.15 Very bright draperies and rays (greenish white) for about 60° around northern horizon. Formation in east and overhead less distinct now but diffuse surfaces covering nearly the whole sky.

7.25 Similar but much less brilliant.

7.40 Same.

8.20 Brighter again. Rays and diffuse surfaces over whole sky (greenish white—no red now). Particularly bright surfaces in Orion.

8.45 Bright. Arc in north (without rays). Rays near horizon in east and west and some in south. Also short rays over most of sky which vary. Rays plainly visible in immediate vicinity of moon.

9.05 Arc in north faint. Rays from east to west and diffuse surfaces over most of southern sky.

9.50 Bright glow near eastern horizon with some ill-defined rays extending overhead and changing rapidly. Also some scattered diffuse surfaces. Altogether not so extensive or bright as before.

10.25 High arc in north.

10.50 Bright rays again in east, north and west extending to zenith.

11.10 Clouds prevented further observations.

J. F. Heard

The Ptolemaic and Copernican Theories

Some persons are inclined to think of the publication of Ptolemy's *Almagest* about the middle of the second century of our era as definitely marking the triumph of the geocentric theory of the universe over all opposing views; and that, in a similar way, the year 1543,

wherein the *De Revolutionibus* of Copernicus was given to the world, was the time at which the sun was by general consent enthroned as the ruler of our universe and the earth was assigned a humble place in the family of planets.

As a matter of fact the change from one theory to the other constituted a revolution in philosophical thought, and a general radical conversion of the people of the world, or of a nation, does not occur suddenly at any definite time, it requires centuries to bring it about. Actually instruction in the Ptolemaic as well as the Copernican theory was continued in the chief colleges of Great Britain and America for more than two hundred years after the death of Copernicus.

The immediate cause of this sermonizing has been the perusal of a book entitled *Copernicus the Founder of Modern Astronomy* by Angus Armitage. (London: George Allen and Unwin, 1938) It is a useful contribution to the history of astronomy as heretofore there has been a lack of adequate information in English on this subject. Surely there should also be an English translation of Copernicus's famous work.

I take the liberty of quoting the first few sentences of the new book:

> Of all the age-long problems that have prompted human inquiry, there is none whose progressive elucidation has contributed more to the enlargement of scientific insight than that of tracing regularity in the motions of the heavenly bodies. In this immemorial quest for the secrets of cosmic order, the name of Copernicus stands for a crisis and a revaluation, but not for a discontinuity. For the problem upon which he expended half a lifetime of intellectual labour was, even in his day, already of ancient standing; moreover, the technique which he employed, and much of the data on which he relied, in his attempt to devise a new solution for it, and many of the preconceptions with which he approached his task, were an inheritance from antiquity.

A Few Florida (Perhaps *Florid*) Notes

The Milky Way in Florida—in the Parlor.—In a large advertisement in one of the daily papers was a picture showing a large bungalow surrounded by many apparently contented cows, and beneath it was the inscription: "The Suwanee herd and milking parlor, 7800 Fourth Street North".

Remarkable Chickens.—We have all heard of the man who was

"Clothed and in his right mind", but in a Florida town there are "Live and dressed chickens".

What does this Sign Mean?—"Keep out U.S. employees only."

The Caldron Boils.—Under a picture of two pleasant-looking women each wearing a fez was: "Two officers in most prominent places at Selama Caldron's banquet . . . (left) Mighty Chosen One of local Caldron group and Supreme Mighty Chosen One of Selama Caldrons. . . . At the banquet were: Past Supreme Mighty Chosen One, Supreme Yusef, Supreme Alchemist of Mystic Order of Veiled Prophets of the Enchanted Realm, and Monarch of Selama Grotto."

Thus besides the sunshine and flowers, citrus fruits and kindly people, there are many other things to be seen and enjoyed. A wonderful country! C.A.C.

Harvard Summer Conference on Astronomy

From Dr. Fletcher Watson, Secretary of the Harvard Observatory, we have received the following announcement:

Between July 5th and August 15th the fourth series of Summer Conferences on Astronomy will be held at the Harvard Observatory. During the six-week period of the Conferences the regular staff of the Harvard Observatory will be supplemented by distinguished visiting astronomers. It is hoped that many astronomers will take advantage of the splendid opportunities for guidance and research that are offered during the period of the Conferences. Visitors who wish to make use of the plate collection or the instrumental equipment of the Observatory will be accommodated to the greatest possible extent.

Dr. Svein Rosseland, Director of the Institute of Theoretical Astrophysics, Oslo, will lecture on Stellar Structure and Stellar Variation—the application of atomic physics and modern hydrodynamical theory to the internal structure of the stars and the variability of their light. Dr. J. H. Oort, of the University Observatory, Leiden, will discuss the Distribution and Motion of the Stars—the distribution of stars in high galactic latitudes, the density distribution on the plane of the galaxy, galactic rotation and the dynamics of spiral structure. A Survey of Modern Problems in Celestial Mechanics will be given by Prof. E. F. Freundlich, formerly of Potsdam and Istanbul, now Professor of Astronomy at the University of Prague. Dr. Freundlich will discuss recent advances in classical celestial mechanics and some of the dynamical problems of star clusters and galaxies.

Dr. Shapley will be in charge of the informal discussions of current astronomical topics at the Hollow Square Conferences. The Conference on Special

Problems offers a diversity of subjects: Dr. Menzel will consider the problems of the chromosphere; Dr. Brian O'Brien, Professor of Physiological Optics at the University of Rochester, will discuss solar radiation and its influence on the earth's upper atmosphere; Dr. Zdenek Kopal, of the University of Prague, will present a treatment of eclipsing binaries with special reference to stellar structure; and Dr. Watson will consider the astronomical significance of small solid bodies.

Opportunity for guided research will be provided by Dr. Bok on Stellar Statistics, Dr. Menzel and Dr. Sterne on Astrophysics, Dr. Whipple on Meteors, Dr. Kopal on Eclipsing Binaries, and Dr. Dimitroff on Photoelectric Photometry. An elementary course on stellar astronomy, given by Dr. Freeman D. Miller of Denison Observatory, will deal with the general characteristics of stars, star clusters, and galaxies and with problems in astrophysics.

Through special arrangement with the Summer School exceptionally low rates for auditing privileges can be offered. For details inquire of the Harvard Observatory.

Preservation of Herschel's Observatory House

A number of members have called attention to a recent action taken to assure the preservation of Herschel's Observatory House. The following notice from an English newspaper was sent us by one of our English members.

Observatory House, Slough, Bucks, historic home of Sir William Herschel, who in 1781 discovered the planet Uranus, is to be preserved.

The Minister of Health has approved an order made by the Slough Town Council, under the Town and Country Planning Act, 1932, the effect of which is that the buildings cannot be demolished without the council's consent. The present owner, the Rev. Sir John C. W. Herschel, wishes that the house should be preserved.

Sir William Herschel, who became Astronomer Royal, came to England from Hanover, and went to live at what became Observatory House, in 1786. On his discovery of Uranus King George III made him King's Astronomer—a new office carrying a salary of £200 a year.

Sir William built on the lawn of his house, in 1789, his famous 40-ft. telescope, the biggest ever erected at that time.

Sir John Herschel, only son of Sir William, born in 1792, lived at the house and also became famous as an astronomer and scientist.

The Buhl Planetarium at Pittsburgh

The Buhl Planetarium and Institute of Popular Science is being erected by the Buhl Foundation in Pittsburgh at a total cost of

$1,070,000. The building, now nearing completion, is located on Pittsburgh's North Side at Federal and West Ohio Street. The site, furnished by the municipality, was formerly occupied by the old Allegheny City Hall. In addition to a Zeiss planetarium, fifth in the United States, and a public observatory, the building will include a main exhibit hall, five smaller halls, a lecture hall seating 250 persons, space for amateur telescope makers, offices, shops and preparation rooms.

Wherever possible, exhibits will be moving and operable by the visitor. They will show the development and recent achievements of modern science, with its latest applications.

James Stokley, associate director in charge of astronomy in The Franklin Institute of Philadelphia, has been appointed director of the Planetarium and Institute. The Institute is expected to open in September.

The Fels Planetarium, of the Franklin Institute will have, as its new director, Mr. Wagner Schlesinger. Mr. Schlesinger has been a member of the Fels Planetarium staff since its opening, and had previously been on the staff of the Adler Planetarium. Earlier he was a radio engineer and industrial physicist, with astronomy as an avocation. He is the son of Professor Frank Schlesinger, Director of the Yale Observatory.

COMET VAISALA (1939b)

Recently Professor Y. Väisälä, of Turku, Finland, discovered a very faint object, supposedly an asteroid. The object was designated, in the standard asteroid notation, as 1939 CB. (In this asteroid notation the 1939 gives the year of discovery, the letter C, the third letter in the alphabet, indicates that the discovery occurred in the third "half-month" of the year, i.e., in the first half of February, while the B indicates this was the second asteroid discovered in that half month.)

On March 18, the Central Bureau of the I.A.U. cabled to Harvard that Professor Väisälä has discovered that the "asteroid" is really a comet. While a detailed orbit is not yet given, the object is described as diffuse, of magnitude 15, and period 10 years. Miss L. Oterma gives the following ephemeris:

PLATE VI

Winter 1938-1939 at the David Dunlap Observatory.
Shovelling Snow; the Path to the Dome; the Observatory Road.

		α (1950)	δ (1950)	r	Δ
March	30	$9^h\ 44.1^m$	$+24°\ 37$	1.785	0.965
April	7	9 50.9	$+24°\ 53'$		
	15	9 59.8	+24 47		
	23	10 10.7	+24 20		
May	1	10 23.1	+23 34		
	9	10 36.7	+22 30	1.767	1.223

Professor Van Biesbroeck, of Yerkes, has observed this comet, and finds that it has a faint broad tail about 1′ long. It is unusual for a comet to have an observable tail at such a great distance (over 160 million miles) from the sun.

Not in Florida

Last month Professor Chant wrote in Notes and Queries of some of the difficulties of telling the season of the year in Florida. His confreres at the David Dunlap Observatory have had several indications, the past few months, by which a fair guess might be made as to time of year. The three snapshots shown in Plate VI for which we are indebted to Miss Ruth Northcott, illustrate some of the conditions this winter at Richmond Hill. The meteorologists assure us that the Toronto snowfall has been only some ten percent above normal this winter, but it seems to have fallen in such a way as to prove of maximum embarrassment for observing, transportation and snow shovelling. On numerous occasions the road was too badly blocked to get cars up to the observatory; and on two occasions cars which were up were snowed in, and had to be left for a couple of days. The photo showing the flooded condition of the observatory road was not taken near high water level; on trips when the water was over the running boards there was a notable absence of photographers.

F. S. H.

MEETINGS OF THE SOCIETY

AT VANCOUVER

January 10, 1939.—The fifty-ninth regular meeting of the Vancouver Centre was held at 8.15 p.m. in the Science Building of the University of British Columbia.

The newly-elected president, Mr. C. A. McDonald, was in the chair and introduced the speaker of the evening, Dr. Harold D. Smith of the Physics Department of the University of British Columbia. Dr. Smith spoke on "Low Temperatures" dealing with the production, properties and uses of solid carbon dioxide, known in the trade as "dry ice". This substance is produced by purifying and later condensing the flue gases obtained by burning high grade coke under forced draft. Only about 40% of the carbon dioxide is recovered but the energy needed for operating the plant is obtained from the heat of combustion of the coke.

Solid carbon dioxide is used extensively in the soda water industry, in refrigeration of perishables and in the production of shrink fits in the automotive industry. Within fifteen years its uses have doubled many times from the original use of curing warts, so that to-day it is an indispensable article of commerce with over four hundred uses.

An interesting engineering application was described by Dr. Smith in which a freezing mixture of "dry ice" in alcohol was used to cool and contract the forty ton shaft, and so separate it from the two hundred and seventy ton rotor of a generator unit at the Ontario Hydro-Electric Power Plant at Queenston. The suggestion was made that such a procedure might be useful in the construction of shrink fits in large astronomical telescope mountings.

The informal discussion following the address was widely entered into by the members. Mr. McDonald expressed to the speaker the warm appreciation of the meeting.

A. M. Crooker, *Secretary.*

AT VICTORIA

October 26, 1938.—A regular meeting of the Royal Astronomical Society of Canada, Victoria Centre, was held Wednesday, October 26th, in the Y.W.C.A. parlours. The meeting came to order at 8.15 p.m. with the President, Mr. Gordon Shaw, in the chair. Miss Dorothy Humeston gave a brief description of current astronomical phenomena, noting particularly the eclipse of the moon to take place Monday, November 7th. Dr. Petrie reported the latest news regarding satellites *X* and *XI* of Jupiter.

Dr. A. McKellar introduced the speaker of the evening, Dr. Ian M. Cowan, assistant director of the Provincial Museum. Dr. Cowan had chosen as his topic "Origins of the Fauna of British Columbia."

The speaker first reviewed the geological periods of North America, and discussed the geographical features and climate of this continent. The fauna of British Columbia as known to-day developed since the recession of the ice after the great ice age; pre-ice age mammals disappeared and were replaced by fauna from the north, the east and the south. Dr. Cowan stressed the dynamic nature of British Columbia fauna, explaining that in this respect British Columbia is more interesting than any other part of Canada. Many slides were presented to show typical forest-dwelling mammals in our province to-day.

January 18, 1939.—A regular meeting of the Royal Astronomical Society of Canada, Victoria Centre, was held Wednesday, January 18th, 1939, in the Y.W.C.A. Parlours. The meeting came to order at 8.15 p.m. with the President, Mr. Robert Peters, in the chair. Two new members were introduced to the Society, Lieutenant-Colonel F. W. Moore, and Mr. J. G. Bushler. Juniors of the Society were urged to become members of the telescope making section.

The President then introduced the speaker of the evening, Mr. W. A. Thorne of the Dominion Meteorological Observatory. Mr. Thorne, who had chosen as his topic "Pacific Coast Storms" pointed out that meteorological observations, to be of real value, must come from all parts of the globe. Complete records are difficult to secure: first, because large areas are uninhabited, and second, owing to strained international relations, shipping has been lessened and hence upper air data has become relatively unimportant.

The speaker next explained that meteorologists believe there is evidence to show a correlation between sun spot cycles and storms of our planet. It is a fairly well established fact that at a time of a sun spot maximum there is an increase in ultra-violet radiation, which in turn appears to decrease the surface temperature of the earth as a whole. Observers from shipping vessels have recently noted an increase in storms of small diameter and great violence during sun spot minima; not only here on the Pacific Coast, but also in south eastern North America and north eastern Australia.

By use of many interesting slides, Mr. Thorne illustrated various air motions and discontinuities in the upper air, and showed normal winter and summer conditions of air pressures over the Pacific Ocean. The speaker explained reasons for, and showed charts to illustrate cold wave or fog conditions around Vancouver Island and the phenomenon of southwest rather than northwest winds here at Victoria.

The quiz contest of the Annual meeting was continued. Miss Mary Flannigan won the first prize; and Miss Dorothy Humeston, the second prize, a book presented by Dr. R. Petrie.

PHOEBE RIDDLE, *Recorder.*

AT TORONTO

February 7, 1939.—The regular meeting of the Royal Astronomical Society, Toronto Centre, was held in the McLennan Laboratory, University of Toronto, with Mr. S. C. Brown presiding.

The paper of the evening was given by Mr. A. F. Bunker of the Department of Astronomy of the University of Toronto. His subject was "Star Legends of the American Indian".

Mr. Bunker first remarked that in order to appreciate the legends we must forget our knowledge of the gaseous nature of the stars, and, with the Indians, think of the stars as spirits, called by them "manitus". Star clusters were thought to be villages of manitus. Many legends tell how the manitus rewarded Indians here on earth.

A very interesting legend of the Navajo tribe tells of the formation of the sun, earth, and stars. They explained the random distribution of the stars in the following manner. The Indians arranged the stars in patterns of animals but just as they were about to place them in the sky a wolf jumped among them and scattered them into space.

Mr. Bunker related legends about several of the constellations. The legends of the Pleiades as given by three different tribes were very similar. The constellation Corona Borealis was thought to be a council fire watched over by a serpent. Taurus represented to the Seneca tribe, the wigwam of the braves and the fire in front of it. The bowl of the Big Dipper represents a great bear which is chased by three Iroquois brothers, which are the three stars in the handle. In the autumn the brothers think that they are about to catch the bear. They shoot him with a bow and arrow. The blood of the bear is believed to colour the trees red. The heat of the chase is so great that it melts the fat of the bear's body, and this colours some of the trees yellow. Then the bear hibernates for the winter.

A brief discussion followed Mr. Bunker's address.

Mr. Hassard suggested that the English significance of the constellation names be published in the Handbook. He also brought to the attention of the members that Venus is particularly brilliant and beautiful in the morning sky, and well worth observing.

Dr. P. M. Millman continued his course with a lecture on "The Depths of Space". He clearly outlined the observational facts connected with the external galaxies. These were three in number:

1. All faint galaxies show a displacement of lines to the red, and the red shift, $\frac{d\lambda}{\lambda}$, is constant for each galaxy.

2. The red shifts become greater as the apparent luminosities of the galaxies becomes fainter.

3. The number of galaxies observed per square degree increases with increasing faintness of these objects.

He then discussed various aspects of these facts in the light of different assumptions. This discussion is to be continued in the next lecture.

February 21, 1939.—The regular meeting of the Royal Astronomical Society of Canada, Toronto Centre, was held in the McLennan Laboratory, University of Toronto, on Tuesday evening, February 21. Mr. J. R. Collins was in the chair.

The speaker of the evening was Miss Elizabeth Allin, Ph.D., of the Department of Physics, University of Toronto. Her subject was "Recent Advances in Nuclear Physics". Miss Allin gave a brief account of the early work which led to our present conception of the atom as being made up of a heavy nucleus of protons and neutrons and outer electrons. This lecture will be printed in full in the JOURNAL.

Continuing his series of lectures, Dr. Millman discussed the two alternatives to which we are led by the observational data of the external galaxies. *Either*—red shifts do not represent velocities, in which case there is a linear relation between red shift and distance, and the average density of galaxies in space is roughly uniform; but there is no known physical principle which will account for the red shifts. *Or*—red shifts are velocities of recession, in which case they are accounted for by well-known physical laws; but we now lose the linear relation between red shift and distance, and the average density of galaxies in space is not uniform. Dr. Millman next discussed four-dimensional space-time, and considered the concept of curvature in this space as given by Riemannian geometry. This geometry applied to the basic principles of Relativistic Cosmology leads to a number of possible universes, none of which are entirely satisfactory.

March 7, 1939.—The regular meeting of the Royal Astronomical Society of Canada, Toronto Centre, was held on Tuesday, March 7, in the McLennan Laboratory, University of Toronto. Mr. S. C. Brown was in the chair.

The following were elected to membership in the Toronto Centre: Mr. A. Merkur, 350 Palmerston Blvd., Toronto; Prof. J. A. Toomer, Department of Metallurgy, University of Toronto.

The speaker of the evening was Dr. Wendell Hewson of the Meteorological Service of Canada. His subject was, "Recent Investigations of the Aurora". Dr. Hewson first described the types of aurora that have been observed. These are classified in two main types, ray and non-ray. The ray type of aurora is further classified as draperies, arcs and coronae; the non-ray type as homogeneous bands, homogeneous arcs, and pulsating surfaces.

The geographical distribution of the aurora is found to give lines of equal auroral frequency which are roughly circles around the point where the axis of the magnetic dipole which approximates to the earth's magnetic field cuts the earth's surface. The zone of maximum frequency occurs at about 23° from this magnetic axis.

There are three main variations in auroral activity: first, a diurnal variation with a maximum about 1 a.m. local time; second, a 27 day variation, corresponding to the sun's period of rotation; third, an eleven year period, corresponding to the sun-spot cycle.

The heights of the aurorae are obtained from the displacements of the aurora relative to the background stars on photographs taken simultaneously from two stations whose distance apart may be as great as 100 miles. It is found that the lower limits of the aurorae are most frequently observed at 100 km. and 106 km. This double maximum has been explained as being due to atmospheric tides. Very high aurorae occur in the sunlit atmosphere, although the surface is in darkness. The height at which the sunlit aurorae most frequently occur is about 400 km.

The spectrum of the aurora is characterized by the green line at λ 5577, which was found by the late J. C. McLennan to be due to oxygen with helium and neon in excess. Some 85 lines have been studied in the region from 8100 A. to 3100 A. A large number of these lines have been identified as due to nitrogen and oxygen atoms in different states of ionization. It is interesting to note that no helium or hydrogen lines have been found.

In 1881 Goldstein and Birkeland suggested that the aurorae are caused by electrically charged particles emitted by the sun and influenced by the earth's magnetic field. Birkeland, in 1896, by bombarding a magnetized sphere with cathode rays, got a distribution of cathode rays similar to the aurora. C. Störmer made a mathematical analysis of the motion of an electrically charged particle in the earth's magnetic field. This led to the result that the charged particles can only enter near the poles and come in on the night side of the earth. Brüche showed that the trajectories could be reproduced in the laboratory with surprising accuracy. There are objections to Störmer's theory: the zone of maximum auroral frequency is predicted to be 3°, 5°, or 18°, whereas it is actually found to be 23° from the magnetic axis; doubts have been raised by A. Schuster as to whether the electronic bundles emitted by the sun could reach the earth without dissipating by electrostatic repulsion. However, this theory explains how the aurora can occur during the night and shows how the horseshoe forms of draperies originate.

Sounds associated with the aurora have not been theoretically explained but must be due to a secondary discharge in the lower atmosphere.

Dr. Millman discussed a recent paper by J. L. Greenstein, published in the *Astrophysical Journal*. Hubble, in computing the effect of redshift on apparent magnitudes, assumed that the intensity distribution in an average nebular spectrum corresponded to black body radiation at temperature 6000°A. Greenstein points out that this temperature is open to question. From the spectrum of the Andromeda Nebula, the colour temperatures of some 160 galaxies computed by Stebbins and Whitford, and colour indices determined at Mt. Wilson and Harvard, it would seem that the effective temperature should be much lower. Another source of uncertainty lies in the exact magnitude scale at the limit of the Mt. Wilson plates. The conclusion is that the observational evidence is not yet good enough to tell what the redshifts mean, or to determine the type of universe in which we live. Dr. Millman concluded his lecture by a brief description of a kinematical conception of the universe developed by Milne.

RUTH J. NORTHCOTT, *Recorder*.

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